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THE INSTITUTION OF PRODUCTION ENGINEERS

PRECISION MEASUREMENT BY OPTICAL METHODS

Paper to be presented to the Institution, London Section, 9th February, 1945, by K. J. Hume, B.Sc., A.M.I.P.E.

THE science of Physics with its many branches is the basis of all engineering. As far as Production engineering is concerned, it will generally be accepted that the principles of statics, dynamics, hydrostatics, electricity, magnetism, etc., can be traced in many applications.

The field of precision measurement as applied to modern engineering has brought the engineer into touch with even more scientific principles than those just mentioned.

Optics plays an increasingly important part in the methods used to control accurate production. This seems quite logical when it is considered that the eye is usually the final instrument in any measurement and assistance by optical methods has a more direct and often a more exact application than other methods.

The three most important principles of optics met with in precision measurement are reflection, refraction, and interference, and with apologies to those to whom it may appear elementary I propose to start with a brief description of these principles.

Reflection.

I shall confine my descriptions mainly to reflection at plane surfaces, as although spherical mirrors have certain applications to measuring instruments, the additional factors involved will be fairly obvious without detailed discussion. Fig 1 (*a*) illustrates the first law of reflection, *i.e.*, the incident and reflected rays make equal angles θ with the normal to the surface, both rays and the normal lying in one plane. It is as well to point out here that rays of light are conventionally represented as single lines but the extension of the principles to a beam of light or ' pencil of rays,' as it is called, is fairly obvious.

It will be seen from Fig. 1 (*b*) that if the mirror is tilted through an angle $\delta\theta$ the reflected ray is deflected by twice this angle since both the incident and the reflected ray now make an angle $\theta + \delta\theta$ with the normal and the angle between them is increased by $2\delta\theta$.

This phenomenon is widely utilised in measuring instruments including some of those of the highest accuracy.

E. M. Eden of the National Physical Laboratory introduced a secondary fixed mirror in front of the tilting mirror—Fig. 1 (*c*).

This returns the first reflected ray to the tilting mirror and the final reflected ray deflects through four times the angle moved through by the mirror. The sensitivity of the single reflecting mirror is thus doubled.

The ideal type of mirror for measuring instruments is a surface reflector which can give only a single reflection. A back reflecting mirror as shown in Fig. 1 (*d*) will give a double reflection, one from the front surface and one from the back. Although the front surface reflection is usually much weaker than that from the silvered back surface it often produces confusing double images.

Where a back surface reflector is used the front surface is sometimes made deliberately at a slight angle to the back so that the front surface image is outside the field of view.

Concave spherical mirrors are sometimes used, their advantage being that they will bring a beam of light to a sharp focus without using lenses in the system. The same rules regarding deflection of rays, etc., apply as in the case of plane mirrors.

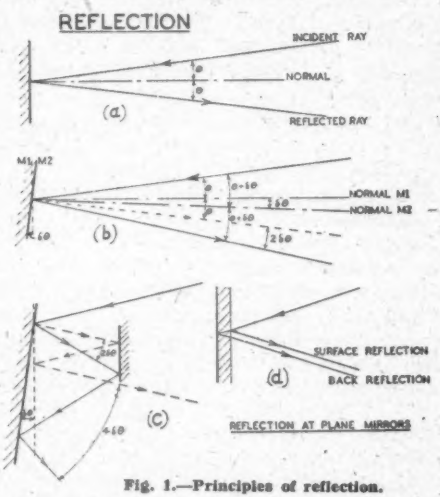

Fig. 1.—Principles of reflection.

Convex and parabolic mirrors have, as far as I know, no applications although the possibility of using a parabolic mirror to obtain a parallel beam of light should not be overlooked.

Refraction.

The phenomenon of a ray of light bending when passing from air to a denser medium or vice versa is well known. The classic examples of the apparent bending of a stick in water and the coin hidden by the rim of a dish becoming visible when water is added are hardy annuals as parlour tricks.

Fig. 2 (*a*) illustrates a ray of light passing from air into a block of glass having a plane surface. The amount by which the ray is

bent or refracted is governed by a definite law. For any two given media *e.g.*, air and any particular glass the relationship is given by $\frac{\sin i}{\sin r}$ = constant (μ), i and r being the angles that the incident and refracted rays respectively make with the normal to the surface. This constant is called the refractive index for the two media. The refractive index for a single medium, *e.g.*, a particular kind of glass is defined with air as the other medium. It will be observed that the ray always bends towards the normal when passing from a rare to a denser medium and away from the normal when passing from a dense to a rarer medium.

Fig. 2 (*b*) shows how a ray of light is bent by passing through a triangular prism. Different wavelengths or colours of light are refracted through different angles and this causes the well known spectrum, first demonstrated by Newton, which can be obtained from white light. It is this fact also which causes quite a number of the difficulties of lens design and manufacture in the form of chromatic abberation which will be dealt with later.

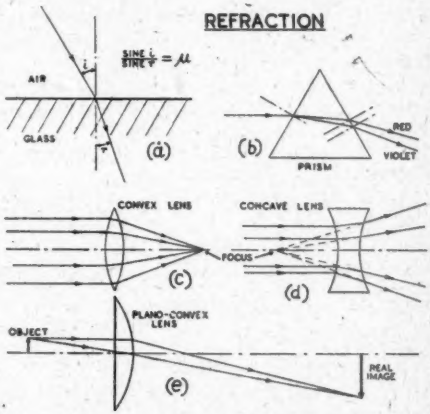

Fig. 2.—Principles of refraction.

I must mention in passing that some of the optical definitions and formulae which I give may not, in all cases, be exactly or completely true without reservation. For instance, it will be apparent that the refractive index of a medium is not the same for every wavelength ; but such details would lead us too far into the realm of theoretical physics and outside the scope of this paper.

A lens may be considered in section as an infinite number of truncated triangular prisms whose apex angles gradually decrease from the edge to the centre.

A convex lens can be regarded as any lens which is thicker at the centre than the edges, irrespective of whether both faces are convex, one plane and one convex or one concave and one convex, and this type of lens will converge a beam of light falling on it.

A beam parallel to the optical axis will pass through a point on the other side of the lens called the principal focus and the distance of this point from a plane defined in the lens is the focal length, a very important dimension (Fig. 2*c*).

A concave lens, thinner at the centre than the edges, diverges a beam of light falling on it. A parallel beam viewed through the lens appears to come from a point behind the lens—Fig. 2 (*d*).

Only a convex lens, or in practice a combination of lenses equivalent to a convex lens, will produce a real image, that is to say an image which can be thrown on to a screen. This is shown in Fig. 2 (*e*).

The different refractions of the component colours of white light have the effect of producing a slightly blurred image with coloured edges. This is the chromatic abberation previously mentioned which becomes a serious matter when magnifications greater than three or four times are being used.

Other factors come into play with higher magnifications and cause distortions such as spherical abberation, astigmatism, coma, etc., which I shall not try to describe.

It is to combat these distortions that all but the simplest and crudest of lens systems are built up of several lenses made of various kinds of glass with different refractive indices. The design of a first class lens system for a particular purpose is a specialists job, involving considerable practical knowledge and experiment together with an immense amount of mathematical research and calculation.

Interference.

The propagation of light, or rather the explanation of it, has passed through several theories in the last few centuries. The pendulum has swung between two main theories, the corpuscular theory and the wave theory. The corpuscular theory states that light consists of particles of some sort emitted from a source, reflected, refracted, dispersed, etc., and finally entering the eye of an observer. The wave theory states that light is a transverse wave motion of an electro-magnetic nature in an undefined medium sometimes called aether and that this wave motion is transmitted in a similar manner to waves on the surface of a liquid. Since the days of Newton the wave theory has established its position more and more firmly until the advent of Planck's quantum theory which has again raised uncertainty and scientific controversy on the subject.

For all the light phenomena with which we are concerned, however, the wave theory is perfectly suitable and, after all, a theory which will explain and predict phenomena accurately has served its purpose well.

Fig. 3 (*a*) represents two light waves 180° out of phase. At 3 (*b*) these waves are assumed to be travelling along the same line and in the same plane. It can be seen that for every point on one wave there is an equal and opposite point on the other wave. The two waves will therefore interfere or cancel each other out completely and no light will be seen along the line of propagation. Fig. 3 (*c*) shows two waves exactly in phase, the net result of which, as seen in Fig. 3 (*d*), is a wave of double amplitude produced by the addition of the two waves at each point. The wavelength λ (Lambda) depends on the frequency and in the case of visible light is of the order of 0.00002 inch.

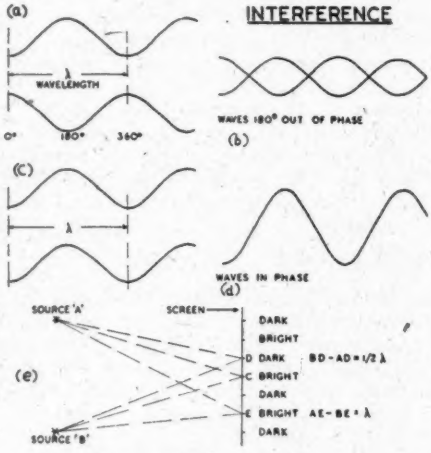

Fig. 3.—Principles of interference.

Imagine two point sources of light A and B, Fig. 3 (*e*) transmitting light on to a screen in plane D.C.E. If the sources are assumed to be exactly in phase at A and B, at point C on the screen equidistant from A and B the rays A C and B C will be in phase and will reinforce each other, producing a bright band. At a point D where the distance A D is less than B D by $\frac{1}{2}\ \lambda$ the waves will be 180° out of phase as at Fig. 3 (*a* and *b*) and a dark band will result. At a point E where the path difference AE — BE is exactly one wavelength the waves will be in phase again and E will be a bright band. Thus alternate bright and dark bands will appear up and down the screen according to whether the path difference from A and B is an even or odd number of half-wavelengths respectively.

It is only possible to obtain interference phenomena when the two light sources are formed by splitting up a single source. The reason for this is that a source of light consists of waves of all possible phases and orientations and therefore two separate sources can never be consistent in their phase relationship. Any interference which chances to be present in such circumstances is completely masked by the random element.

If, however, light from a single source is split into two parts, for

instance by partial reflection and partial transmission at a plane glass surface, interference phenomena can be obtained under certain circumstances when the two rays of light come together again.

In this case, each wave in one of the parts has its exact counterpart in the other part and interference will result if these two parts are brought together out of phase.

Details of a typical method of splitting light in this manner will be dealt with later when the application of interference to the measurement of surface flatness is described.

I shall now describe some of the optical instruments in use today and endeavour to show how the foregoing principles are applied.

The classification adopted will at first glance probably seem rather strange.

I have arranged instruments in categories depending on the optical systems and principles involved and consequently several instruments making the same type of measurement will appear in different categories. There are, for instance, several different principles on which an optical end gauge comparator can be based and these are dealt with separately.

Projectors and Microscopes.

This class of equipment is probably the best known and most widely used of all optical measuring instruments and is today available in many different types to suit various requirements. Projectors vary from the small bench and transportable types using microscope objectives to large horizontal and vertical types using specially designed lenses capable of giving an almost undistorted image of a 3 inch diameter object.

Microscopes are more restricted in field size but vary from a straightforward microscope fitted with a scale or angle graticule to quite versatile instruments incorporating co-ordinate work tables circular dividing work tables, magazine graticule eyepieces and equipment for projecting an image on a screen.

The principle underlying instruments in this category is the direct magnification of an object for the purpose of measuring its dimensions more accurately than is possible with the unaided eye, the measurement being made by scale at the screen against a standard diagram or other datum, or by micrometric measurement of the movement of the object when it is aligned with different parts of a master diagram or graticule.

In general, one of the fundamental conditions for accurate projection of most engineering objects is parallelism of the illuminating beam. This is of course an ideal which is not completely attainable in practice. Theoretically a parallel beam can only be produced by collimation of the rays from an infinitely small source of light

and there always has to be a compromise between providing the smallest possible source and providing sufficient light for comfortable observation. Parallel light is necessary in particular for the projection of cylindrical objects and screw threads, otherwise erroneous measurement of diameters and profiles will be obtained

The measurement of screw threads is one of the commonest functions of a projector and it is one which is not as straight-forward as might at first appear. The aim of screw thread projection is to obtain a true image of an axial section of the thread and the ideal result would be obtained if a thin lamina cut from an axial plane were projected. Interference caused by the helical nature of a thread prevents a true image being formed if the thread axis is placed normally across a co-axial collimating and projection lens system. A satisfactory axial section is obtained in most cases by inclining the collimating beam to the projection axis at the mean helix angle of the thread.

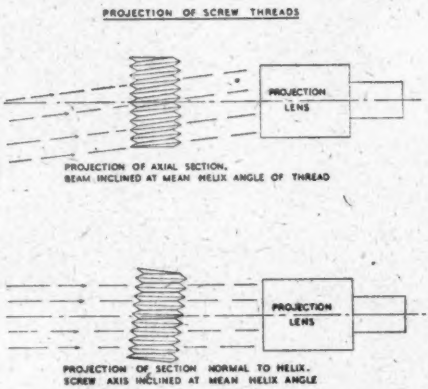
PROJECTION OF SCREW THREADS
PROJECTION LENS
PROJECTION OF AXIAL SECTION.
BEAM INCLINED AT MEAN HELIX ANGLE OF THREAD
PROJECTION LENS
PROJECTION OF SECTION NORMAL TO HELIX.
SCREW AXIS INCLINED AT MEAN HELIX ANGLE

Fig. 4.—Projection of screw threads.

This method is used in some projectors and microscopes and produces the most nearly correct image, as the proportions of thread profiles are defined in the axial plane. Other instruments, however, produce the image by keeping the collimating and projection axes co-axial and inclining the thread to this axis by its mean helix angle (Fig. 4). The image thus produced represents a section normal to the thread helix and differs theoretically from the thread form as defined. The amount of difference varies for each particular helix angle and cannot be overcome by modification of the standard thread form diagram or graticule. Fortunately, in most cases the difference in profile between the axial and normal sections is very small and barely exceeds the inaccuracies of observation. This is, however, a point which should be clearly understood and taken into account if any abnormal helix angles are being dealt with.

The helix angle of a thread varies between the crest and root and whilst it is accurate enough to work on the mean helix angle for

standard threads, special threads of small diameter and coarse pitch will not produce a satisfactory image by ordinary projection methods. A clever optical system devised by C. F. Smith utilising a line source of light, an inclined slit and a combination of cylindrical and spherical lenses, gives a beam whose helix angle varies in the depth of thread and produces in such cases a well defined image of a normal section which is unobtainable by other methods.

The source of light used on projectors varies on different models but most manufacturers favour the low voltage close coiled or grid filament lamp. This choice is largely a question of convenience and universal application, as this type of lamp is easily run off a transformer. A D.C. arc used in conjunction with a fairly long focus condenser (about 7 inches) gives a good parallel beam combined with adequate illumination and is probably the best method if the slight inconvenience of an arc lamp is no objection. In any case the inconvenience is negligible if a good clockwork feed mechanism is used. Fig. 5 shows the optical system of a British projector which is constructed in a girder framework, the projected beam being reflected to the top of the framework on to a large surface-reflection mirror and back again on to a horizontal screen. The projection lens shown on the right of this illustration is one of 10 inches focal length giving an image of a 3 inch diameter field at 25 magnification with a total distortion of less than 0.0002 inch measured in the object plane. This is an excellent example of the skill of British optical designers and craftsmen in producing a lens to do a specified job which no one had succeeded in doing before. In fact, the accuracy attained by the first of these lenses over a 3 inch field was better than that of many existing projection lenses over a field of less than 2 inches diameter.

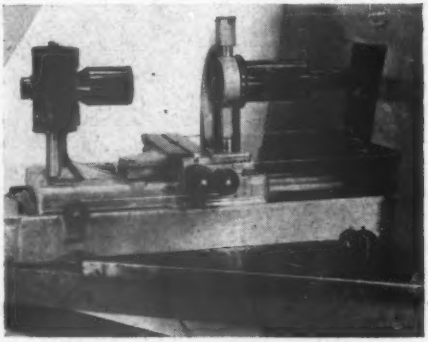

Fig. 5.—Optical system of a projector.

Other projectors of smaller field range are designed to be transportable and produce an image by transmitted light on a translucent glass screen. These usually operate with short focus projection lenses and reflect the beam within the cabinet on to the

screen. Obvious disadvantages of this type are the restriction of field diameter (usually about $\frac{1}{4}$ inch at 50 magnification) and the necessity of using transparent material for projection diagrams. For certain purposes, however, the convenience of operation makes this type of projector extremely useful, particularly in the workshop where the operator can check his work for himself and move the projector from the vicinity of one machine to another. (See Fig. 6).

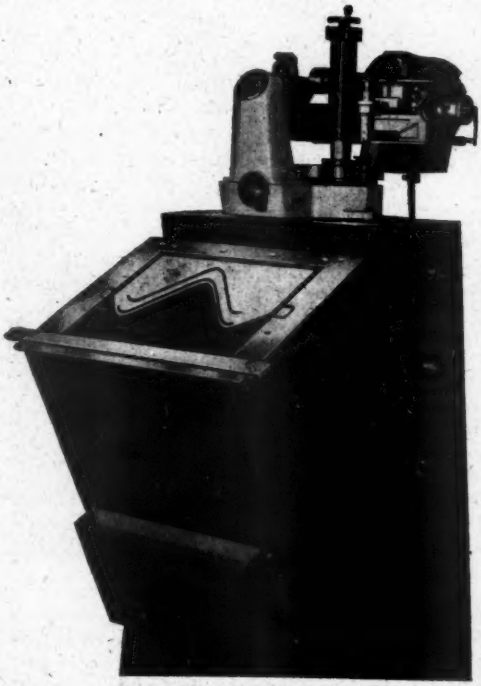

Fig. 6.—Transportable projector.

Toolmakers' microscopes are designed on similar optical principles to projectors except that the image is not thrown on to a screen, except by an auxilliary attachment, but is viewed directly through an eyepiece. Various graticules of thread forms, angles, etc., are arranged to lie in the focal plane of the eyepiece and appear superimposed on the image of the object under examination. Coordinate movements of the work stage, controlled by micrometers and slip gauges, compensate in some respects for restriction of field and make these instruments very convenient for the measurement of threads, position and profile gauges. Effective diameters and pitches of threads can be measured with a fair degree of accuracy using the stage micrometers, although for gauge work the accuracy is not as high as that obtained by appropriate mechanical measurement. A typical toolmakers' microscope is shown in Fig. 7.

Before concluding the discussion of projectors and microscopes

it is worth mentioning some of the optical conditions which must be fulfilled in the design of lenses for these instruments. The first consideration must be to produce a colour free and undistorted image in a flat plane. Freedom from colour is most important, for an image which is fringed with colour prevents accurate measurement and contributes to diffusion of outline which is usually present at the same time. Astigmatism is an error which is difficult to eliminate towards the edges of the field and can best be detected by projecting a smoked glass plate scribed with two fine lines crossing at right angles. If astigmatism is present it will be found that each line can be brought into sharp focus independently but both cannot be sharply focussed together.

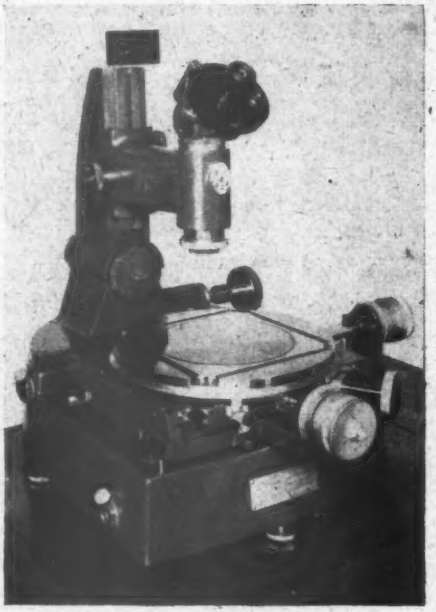

Fig. 7.—Toolmaker's microscope.

Uniform magnification within close limits is of course an absolute necessity and this must be coupled with good general definition over the whole area of the field required. The most critical test for definition is a grid of fine lines scribed on a smoked glass plate. If this is accurately produced and calibrated it can be used to check uniformity of magnification as well as chromatic and spherical abberation, astigmatism and other optical defects which may be present.

Working distance, that is to say the distance between the focal plane and the nearest point of the lens or its mount, is an important consideration on both projectors and microscopes if cylindrical objects are to be examined, as this is the factor limiting the diameter of the object. Usually, a lens intended for screw thread projection will have a longer focal length and smaller field than one designed for general purpose or flat work.

Instruments incorporating the optical magnification of a scale.

Whereas in the type of instrument last considered the optical system was directly concerned with the object being measured, in this category and most of those to follow, optics is a means to an end and has no direct contact with the object itself.

The type of instrument now under consideration can be visualised as an extension of the direct measurement of the dimensions of an object with a scale or with a simple instrument such as a vernier calliper or height gauge. Included in this category are some methods of measuring angles which are elaborated from the use of a simple protractor.

In general these instruments are arranged so that the scale—linear or circular—is observed through a microscope, different readings on the scale corresponding to certain dimensions on the object.

A number of end measuring machines have been designed in the past in which an end bar can be measured directly against a scale or line standard. Although this type of measurement is of little more than academic interest to most production engineers it is really of fundamental importance to engineering standardisation. Our ultimate standard, the Imperial Standard Yard, is of course a line standard and can only be measured optically, whereas the most suitable type of sub-standard for engineers is the end bar whose length is defined as the distance between its parallel end faces. An early step in the chain of standards comparison must therefore be the transition between line and end standards which must be made by a combination of optical and mechanical measurements.

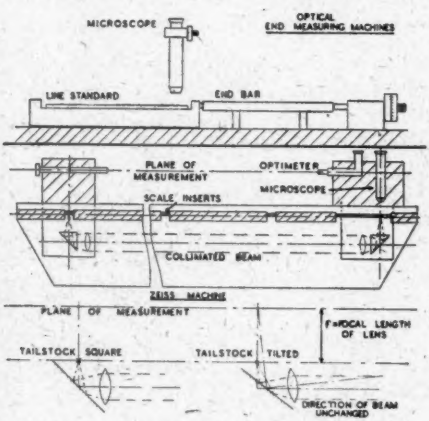

Fig. 8.—Optical end measuring machines.

On some machines designed for this purpose, the line standard is mounted on a carriage moving along the bed of the machine and is viewed through one or more micrometer microscopes fixed to the

bed. The end bar is placed between measuring faces and the distance between the faces controls the position of the carriage and therefore the reading on the standard. A micrometer head with a sensitive indicator, optical or otherwise, is sometimes included. Other machines of this type have the scale fixed and the microscope fitted to the tailstock which contains one of the measuring faces. A universal measuring machine of German manufacture utilises a scale of glass inserts in the bed of the machine. The microscope and the optical indicator are both fitted in the headstock and the position of the tailstock relative to the scale is transmitted optically along the bed to the headstock, where all readings are taken.

This ingenious optical system is also arranged to compensate automatically for slight variations in straightness of the bed which would otherwise introduce errors due to the plane of measurement and the plane of the scale being separated by several inches.

These types of machine are illustrated diagrammatically in Fig. 8.

A vertical comparator developed by Zeiss comprises a four inch glass scale mounted in a cylinder which moves longitudinally on roller bearings. The measuring contact face is fixed to the end of the cylinder and the scale is observed through a microscope. A machine of this type has recently been produced in this country and is shown in Fig. 9. Its chief advantage is that measurements may be made up to a length of four inches without reference to any external standard. The accuracy of measurement on both British and German machines is about 0.00002 inch although the method of reading through the eyepiece is somewhat different in each case. The design of the eyepiece will be described later in connection with a circular scale utilising the same principle.

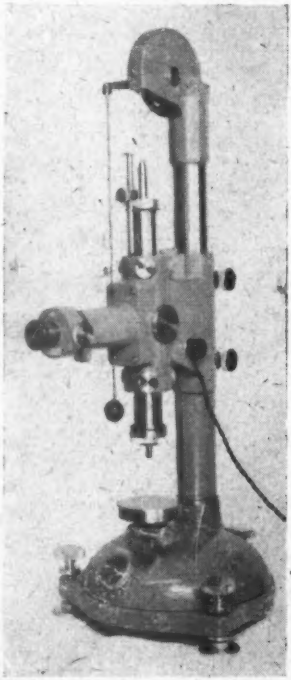

Fig. 9.—Vertical comparator.

The best known machine which utilises the principle of magnified scale readings is the optical dividing head. Once again the Zeiss

machine held the monopoly until shortly before the present war but today there are several British made models available which have in some ways improved upon the German design.

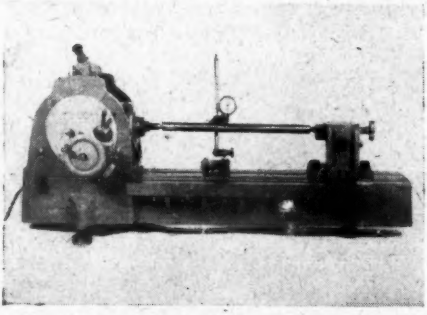

Fig. 10.—Optical dividing head.

The principle of the optical dividing head is a circular scale graduated in degrees or fractions of a degree mounted concentrically on the machine spindle and observed through a microscope. The obvious advantage over the normal shop type of dividing head is that the accuracy does not depend on a worm and wheel which are subject to considerable wear. The optical head retains its accuracy over a long period and, generally speaking, only loses it due to wear on its bearings.

The method of reading the scale varies with different models. On the German and some British dividing heads and optical dividing tables the eyepiece graticule divides one degree into minutes or half minutes ; the position at which a degree line on the circular scale cuts this scale gives the reading to a fraction of a minute. Other British heads utilise an auxiliary scale within the eyepiece. This method of reading is also used on an instrument known as a division tester. This instrument (Fig. 11) can be likened to the scale and microscope of a dividing head removed for external use, enabling the dividing head to be brought to the job where the converse is impracticable or undesirable. It consists of a circular scale mounted on a disc which can itself be mounted on a mandrel, spigot or in other convenient manner. It is not essential for the bore of the disc to be accurately centred, as provision is made for adjusting the scale for concentricity. This concentricity is checked with an indicator on a land adjacent to the scale and fixed accurately concentric with it. It is desirable for the indicator to respond to variations of 0.0001 inch but this does not necessarily follow from the fact that it may be graduated to this figure. The microscope is set up on an adjustable stand in any convenient position from which it can be focussed on the scale. A self contained vertical illuminator is fitted to the objective. The method of reading within the eyepiece is also shown in Fig. 11. A small linear scale, which is seen alongside the main scale moves against a fixed line as the

external knob is rotated and at the same time a triangular index moves more slowly over the main scale.

When the triangular index is exactly symmetrical with one of the main scale graduations, the reading of the secondary scale is taken. This eyepiece is, in effect, a micrometer eyepiece in which the micrometer is read within the ocular, a very convenient feature. The readings on the vertical comparator previously mentioned, as well as several other instruments, are obtained in a similar manner.

An optical bevel protractor, originated by Zeiss and now manufactured in this country, is similar in appearance to the conventional bevel protractor except that the scale is divided on glass and is viewed through a miniature microscope fitted to the body of the instrument. Although this protractor scale is little more than half the diameter of the usual type, readings can be made to an accuracy of about two minutes.

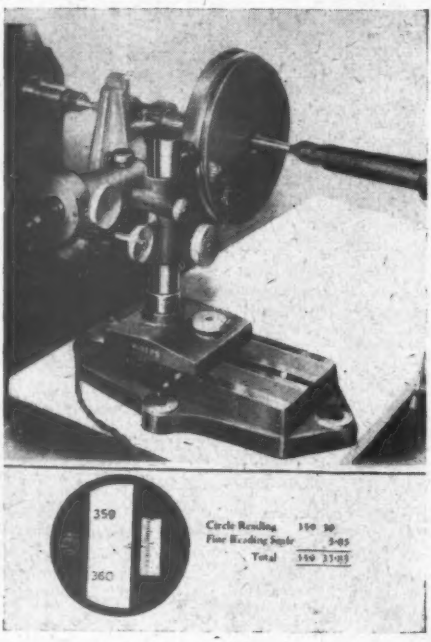

Fig. 11.—Division tester (with ocular reading).

A British firm is now developing an optical system in which two readings at 180° can be made simultaneously on a circular scale, both readings appearing in one eyepiece. This system eliminates inaccuracies due to slight eccentricity of the scale, a source of error difficult to avoid in the construction of dividing apparatus. An eccentricity of only 0.00005 inch on a 5 inch circle introduces 8 seconds error when the scale is read at one position only.

It will be noted from the foregoing descriptions of optical scale instruments that this type is applied chiefly to angular division as

far as production engineering is concerned. This is quite in keeping with present tendencies in engineering measurement where linear measurement is normally carried out against end gauge standards. As a rule these standards can be made up very closely to nominal size and only a short range of comparator scale is necessary. The advantages of a direct reading scale for angular measurement,

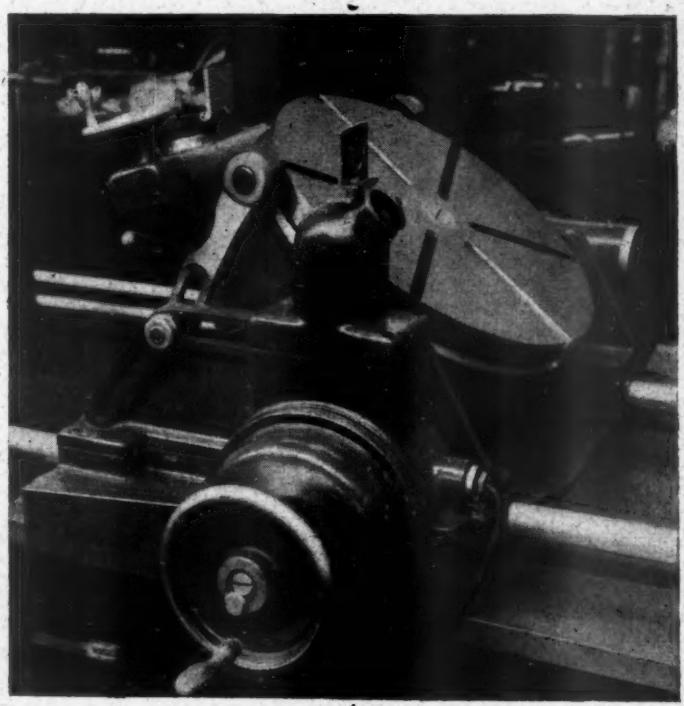

Fig. 12.—Inclinable dividing table.
(Optical scales measure division and inclination).

however, are obvious and this type of apparatus is playing an increasingly important part in accurate production.

Instruments incorporating the optical magnification of a pointer movement.

Although comparatively few instruments of this type are manufactured at the present time, several very successful ones have been

developed in which the mechanical movement of a pointer, hair line or other index is optically magnified to provide a sensitive indicator. Instruments in this and the following category are similar in several respects and it is interesting to note that machines measuring to one millionth of an inch have been made incorporating both principles.

Several other measuring machines have been designed from time to time involving this magnified pointer system but there are few of this type on the general market today. The tendency is for optical magnification of mechanical movement to be carried out by the reflection of a beam in a mirror which is caused to tilt by the mechanical movement. This type of apparatus is described under subsequent headings.

Optical Levers.

The distinction between this type of indicator and those mentioned in the last section is perhaps rather fine. In a way, the projection of a movable index is an optical lever, but the principle being considered under this heading consists of deflection of a beam of light by the movement of a mirror. This method of magnifying small angular deflections has been common practice in the laboratory for very many years, particularly on sensitive electrical instruments where perhaps a few micro-amperes of current must produce a measurable effect and the inertia of the moving parts must therefore be kept to a minimum.

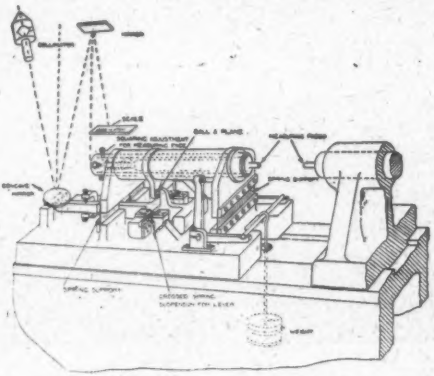

Fig. 13.—N.P.L. millionth comparator.

The advantages of this principle when applied to mechanical measurement will be fairly obvious since it is largely a question of sound design to make a small linear displacement tilt a mirror through an angle suitable for optical lever measurement. The main advantage over pointer magnification is that the beam reflected in the mirror is deflected through twice the angle of mirror deflection. For example, a linear displacement of 0.0001 inch, applied to a mirror at a distance from the fulcrum of $^{1}/_{10}$ inch, will tilt the mirror through an angle of about three and a half minutes

and deflect a spot of light $^1/_{10}$ inch on a scale at 50 inches distance, representing an angle of about seven minutes. Although this may seem an unwieldly distance it can easily be attained if the machine is fixed in position and an overhead mirror is used to reflect the beam back on a scale adjacent to the machine. An N.P.L. millionth machine is designed on these lines although the overall magnification is much higher than the example quoted.

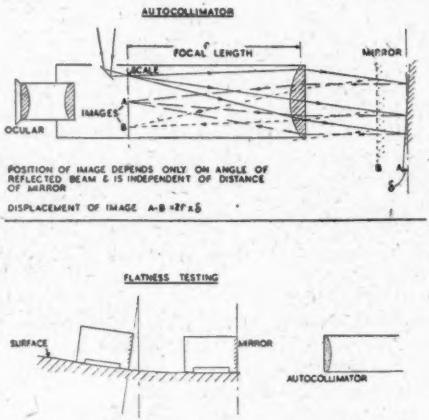

Fig. 14.—Diagrams of auto-collimator and straightness test.

In this machine, which is diagrammatically illustrated in Fig. 13 movement of the left hand contact face is mechanically magnified ten times by a bell crank lever on a crossed strip hinge. This magnified movement is applied to the mirror tilting on a base of $^1/_{10}$ inch, the total optical lever length being about 132 inches. The resultant deflection of the image of a cross wire fixed in front of the collimating lens of the lamp is a quarter of an inch for a variation of one hundred-thousandth of an inch. Readings can be interpolated to one millionth and the machine will repeat to this accuracy if suitable temperature and other precautions are observed.

The optical lever principle has been applied to various other measuring instruments including extensometers, self contained and transportable comparators, etc. Optical comparators of the familiar Zeiss Optimeter type are not dealt with in this section for whilst it is true that they utilise the optical lever principle of tilting a mirror over a short base, the optical system is of the auto-collimator type described in the next section.

Auto-Collimators.

A collimator and telescope can be used to measure angular and lateral displacement between their axes and thus measure the alignment of two locations. In the auto-collimator a single optical system serves both as collimator and telescope. Fig. 14 shows how a scale or graticule placed in the focal plane of the objective lens is

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projected as a parallel beam if it is suitably illuminated. Sometimes the scale is placed to one side of the optical axis and illuminated from the side by a reflecting prism. Alternatively it may be placed in a beam normal to the axis and reflected along the axis by a transparent reflector which will allow the rays reflected back to the instrument to pass on to the eyepiece.

A mirror or other reflecting plane surface, placed in front of the instrument approximately normal to its optical axis, will reflect the parallel beam back into the objective lens. The instrument then acts as a telescope and the rays are brought to a focus in the focal plane of the objective where a second graticule or micrometer eyepiece enables the position of the image to be recorded. If the mirror is tilted through a small angle, the reflected parallel beam will be deflected through twice that angle and the position of the image formed will move proportionally. There are many applications where an auto-collimator can be used with advantage, in fact wherever small variations in angle have to be measured it is often the most convenient method of doing so. Within certain limits the distance of the reflecting surface is unimportant and therefore alignment or parallelism of widely spaced locations can be checked with ease. Whilst this overlaps to some extent the functions of the telescope and target it will not measure lateral displacements but has a much wider application for general angular measurement.

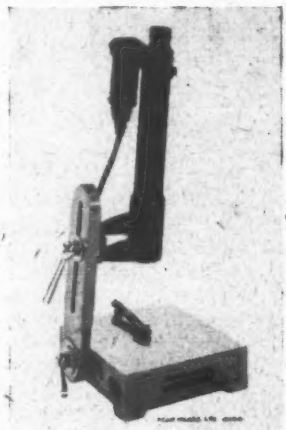


Fig. 15.—Typical auto-collimator.

An auto-collimator can be used for checking straightness or flatness of surface plates, straight edges or machine ways by the method illustrated in Fig. 14. A small block carries the mirror and is traversed along the surface step by step, the angular variations being plotted as variations in straightness.

Parallelism of two surfaces of a gauge or component can be checked by taking readings on each surface or by taking a reading on the surface plate and on other surfaces of the work. It is often possible to obtain two or more readings simultaneously, as a separate image will be observed for each surface if there is any error in parallelism. If all surfaces are truly parallel, only one image is seen.

A well defined image can only be obtained from a polished surface

which is optically flat; ground surfaces will not produce an image. A parallel lapped slip or optical flat placed on the surface being checked will overcome this difficulty, and an ordinary slip gauge will usually serve this purpose quite well.

Angles on work can be measured by setting a standard with a sine bar or master gauge and a great many indicating devices incorporating a small reflector can be made to suit special circumstances, often where other apparatus cannot be satisfactorily applied.

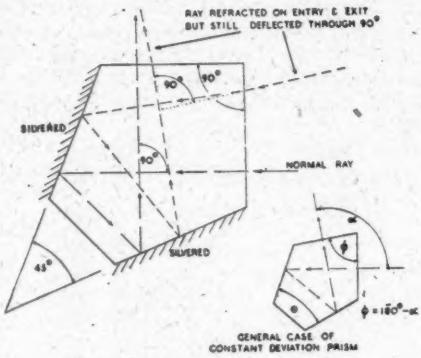


Fig. 16.—Optical square.

A useful accessory to an auto-collimator, when it is required for checking alignments and squareness, is an optical square. This will reflect a beam of light through a right angle even though the incident beam is not truly normal to the face of the prism. Fig. 16 shows diagrammatically how this is done, and it will be seen that variations in the angle of incidence within the physical limitations of the prism are automatically compensated and the emergent beam is always at right angles to the incident beam. The optical square is a special case of the constant deviation prism and theoretically such a prism can be made for any angle between 0° and 180° the angle θ being half ϕ, and the angle ϕ being the supplement of the angle of deflection α.

As previously mentioned, the well known type of optical comparator operates as an auto-collimator. Movement of the plunger tilts a mirror at the base of the tube which reflects the parallel beam projected on to it. A diagram of the optical system is shown in Fig. 17. Just inside the eyepiece is a small scale lying in the focal plane of the objective lens. The reflected image of the scale is seen through the eyepiece moving against a fixed index and a 0.00001 inch movement of the contact point can easily be measured. An additional fitment is sometimes provided which enables the scale to be projected on a translucent screen, thus eliminating the strain of looking into the ocular when the instrument is in constant use.

The use of the auto-collimator principle in precision measure-

ment, whilst well established, is probably not as widely applied as it might be and it is quite possible that many measurements now made by conventional methods will in the future utilise this instrument. Special divisional applications which normally use a divided disc can for instance incorporate a disc with the requisite number of flat sides at appropriate angles. For instance, a twelve sided disc is being manufactured by one firm ; this will cover divisions of 2, 3, 4, 6 and 12 and should be useful in many applications. The essential advantage of this method of division over that using a circular scale is that accurate centreing of such a multi-sided disc is quite unimportant, as the relative angles between its faces are the only standards determining the angle turned through by the work under test. This method is of course not restricted to equi-angular division.

Interferometers.

In a paper of this sort dealing with the general range of optical measuring methods applied to engineering it is very difficult to decide just how far to delve into the science of interferometry, for undoubtedly a paper many times the length of this one could be written on this subject alone, although the present author would not presume to undertake the work.

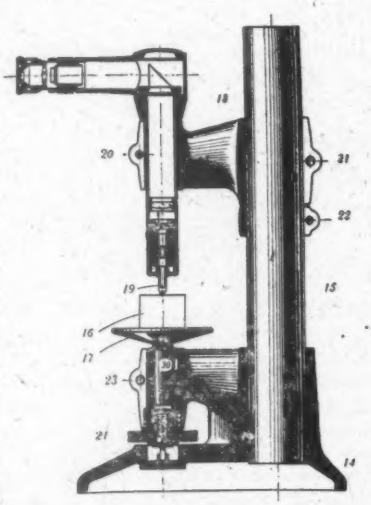


Fig. 17.—Diagram of optical comparator.

Many engineers will be familiar with the application of the optical flat to the inspection and maintenance of slip gauges and other precision lapped surfaces, and some idea of the theory involved in this and other interference phenomena will help in understanding the broad principles of precision measurement by interferometry.

In general, the optical flat will lie at an angle to the surface and a wedge shaped air gap will be present between the two surfaces. This is illustrated in Fig. 18 where a ray of light entering the optical flat is partly reflected in the lower surface. The second ray, by the time it rejoins the first reflected ray will have travelled through a greater distance than the first and may or may not be in phase with it. This will, of course, depend on the size of the gap between the

surfaces and whether the second ray is retarded a whole number of wavelengths or otherwise. Interference will occur if the second ray is half a wavelength out of step with the first. Another complication arises with the reflection of the second ray at the lapped surface since reflection at a dense surface causes a phase change of 180° in the wave front.

It will be seen that as the air gap varies gradually along the wedge, the path difference will vary and will cause the rays to meet alternately in and out of phase. This gives rise to alternate bright and dark bands running parallel to the apex of the wedge. If both surfaces are perfect planes the bands will be quite straight, and successive dark (or bright) bands will be produced by paths differing by one wavelength. Since the gap between surfaces represents half the path, the difference in gap between two dark or two bright bands is one half wavelength and represents approximately 0.00001 inch. If the surface is not perfectly plane the bands will not be straight but will represent a contour map of the surface in units of 0.00001 inch. Thus, assuming the optical flat to be plane to one millionth of an inch, a curvature of the bands amounting to the distance between them represents a concavity or convexity of the other surface of 0.00001 inch and pro rata for other variations.

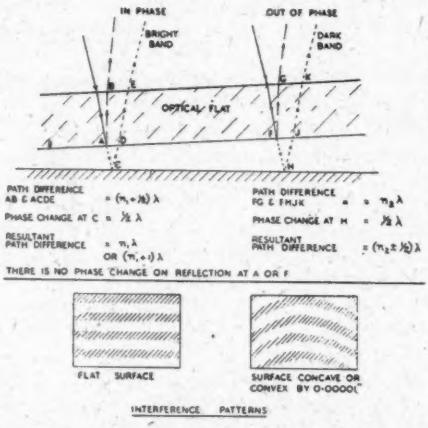

IN PHASE
BRIGHT BAND
OUT OF PHASE
DARK BAND
OPTICAL FLAT
PATH DIFFERENCE AB & ACDE = (n + ½) λ
PHASE CHANGE AT C = ½ λ
RESULTANT PATH DIFFERENCE = n λ OR (n + 1) λ
PATH DIFFERENCE FG & FHJK = n λ
PHASE CHANGE AT H = ½ λ
RESULTANT PATH DIFFERENCE = (n ± ½) λ
THERE IS NO PHASE CHANGE ON REFLECTION AT A OR F
FLAT SURFACE
SURFACE CONCAVE OR CONVEX BY 0·00001"
INTERFERENCE PATTERNS

Fig. 18.—Interference test for flatness

Interferometry is undoubtedly the most accurate method of linear measurement and the principles just described can be extended to compare the lengths of end gauges to a fraction of a millionth of an inch.

Interference methods can, however, do much more than comparative measurement. The wavelength of the light used is in itself an absolute standard of length and if accurately determined in relation to accepted standards can be used for the absolute measurement of end gauges.

Much work has been done in measuring the lengths of existing standards such as the yard and the metre in terms of various wave-

lengths of light. As long ago as 1893, Michelson made the first wavelength determination of the metre and this has since been followed up by observers chiefly in England, France, Germany and Japan, in a number of independent experiments.

This method of standardisation has now reached the stage where the destruction of all existing Primary standards of length would cause no technical inconvenience to the world.

In fact, the abolition of existing fragile standards which are subject to secular changes would be of great benefit to science and engineering. Let us hope that the necessary parliamentary action will be taken before long, for it is certain that when this is done, complete international agreement can be obtained on standards of length which are to all intents and purposes invariable.

I am conscious of having left out of this paper much of importance in optical measurement but I have tried to indicate some of its varied applications.

The application of optics to engineering is an excellent example of the way in which science can directly assist industry.

The success of this demands that the pure scientist shall learn and appreciate the problems of the engineer and that the engineer shall be willing to accept and try out new methods and instruments without prejudice.

The argument that improved measuring methods will mean an unnecessary tightening of working tolerances should not apply with enlightened designers and production engineers.

Such improvements do imply, however, that in most cases more accurate production is possible with consequent improvement in the finished product.

Members will no doubt remember the interesting paper given by Mr. Grafton on the use of optical surveying instruments for the measurement and control of large aircraft jigs and fixtures. Here, a bold break with traditional methods in favour of the employment of modern scientific instruments has undoubtedly simplified manufacture as well as guaranteeing the accuracy of the product to hitherto impossible limits.

The development of precision instruments suitable for industrial use has made great strides in this country during the last few years, although at the outbreak of war we were still largely dependent on foreign supplies, mostly German.

This industry is one in which the British can, if they try, attain and keep the lead, for we undoubtedly have in this country some of the best scientists and engineers in the world.

Acknowledgment.

The author wishes to thank the following for providing illustrations :

Messrs. Cooke Troughton and Simms, Ltd. Fig. 10.
Messrs. Adam Hilger, Ltd. Figs. 6 and 15.
Messrs. E. H. Jones (M.T.), Ltd. Figs. 7 and 12 (" *Machinery* " photograph).
The National Physical Laboratory. Fig. 13.
Messrs. Taylor, Taylor and Hobson, Ltd. Fig. 5.
Messrs. E. R. Watts and Son, Ltd. Figs. 9 and 11.
Fig. 17 is from a Zeiss catalogue.

The de Havilland Aircraft Co., Ltd., kindly provided facilities for the preparation of lantern slides.

THE RESEARCH DEPARTMENT ACTIVITIES

QUARTERLY REVIEW—3

Turning Tests.

In addition to the normal rough turning tests very severe duty turning tests have been carried out on selected grades of carbide tools supplied to industry by the leading tool makers. Over 60 different tip materials were tested. Finish turning tests have included a number of finish facing tests and preparation of the equipment for structure orientation tests on diamond tools is proceeding.

Drilling.

The special series of tests comparing the performance of drills supplied by selected British drill makers is now complete and most of the report is in draft form. In addition to the general performance of drills and life tests this report deals with the effects of point thinning and errors in point grinding.

The small capacity drilling dynamometer described in Quarterly Review No. 2, is now in use and results of preliminary tests on the drilling of non-ferrous alloys have been compiled.

Milling.

A limited range of finish milling tests with negative rake cutters has been completed. All the special equipment for general negative rake milling tests is prepared and preliminary tests have commenced. In the absence of a sufficiently powerful milling machine rough face milling tests will be carried out on the heavy duty tool testing lathe. These tests will be commenced as soon as the turning programme can be suspended.

Vibration tests on milling machines working under various conditions have been carried out.

Field Research.

Investigations have been carried out at various works during the past quarter. The investigations included machine tool deflection and vibration tests. The Research Department is extending its field research service to meet any urgent demands arising in industry.

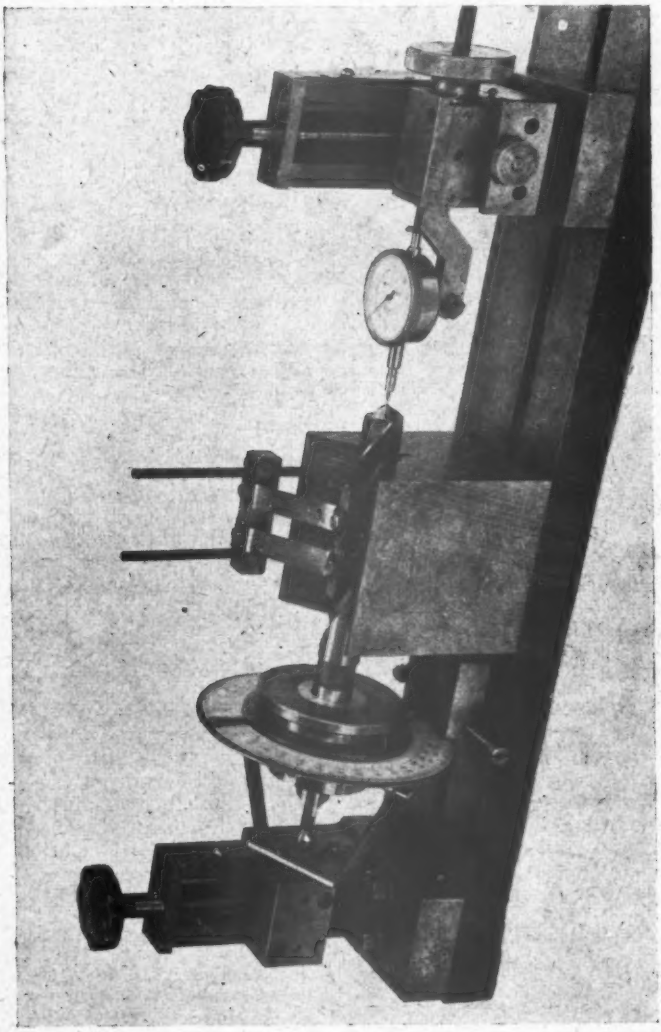


Fig. 1.—Drill point tester

Drill Point Inspection.

In all drilling tests carried out in the Research Department drills are machine ground under very carefully controlled conditions and the points are then checked in the point tester shown in Fig. 1.

One of the most important factors affecting drill performance is relative lip height which, together with the angle of relief *a* can be readily measured at various radii, using the point tester. This instrument consists of a vee block on which the drill rests, while its shank end, carrying a special sleeve and circular protractor is held by springs against a centre. In contact with the ground end of the drill is the sharp feeler of a $\frac{1}{10,000}$ in. dial gauge which can be adjusted vertically and horizontally so that the feeler explores any required radius of the drill. The drill with its sleeve and protractor is rotated by hand, the exact angle of rotation being observed, together with the corresponding relief indicated on the dial gauge. For ordinary testing we maintain relative lip heights within 0.002 in., otherwise even with comparatively coarse feeds the distribution of load between lips becomes very uneven and drill performance is impaired. These limits may be compared with the variations common in practice, not only among drills that have been badly ground by careless users, but among drills as supplied from stocks of reputable makers.

Make of Drill	Drill Dia. at Point	Point Angle	Chisel Edge Angle	Relief Angle						Difference in Lip Height Maximum
				At $\frac{1}{32}$" Rad.		At $\frac{1}{16}$" Rad.		At $\frac{1}{8}$" Rad.		
				Lip 1	Lip 2	Lip 1	Lip 2	Lip 1	Lip 2	
A	.6245"	118°	138°	11°30	10°20	14°20	13°20	22°30	22°30	.004"
B	.6248"	118°	136°	9°0	7°0	12°0	13°40	24°0	23°40	.005"
C	.6256"	127°	138°	20°10	17°0	21°10	19°50	24°20	26°0	.011"

Fig. 2.—Variation between new $\frac{1}{4}$" diameter drills supplied by different makers

The table Fig. 2, gives variations in lip height and values of relief for new $\frac{1}{4}$ in. diameter drills selected at random from supplies received from various makers.

This table reveals many undesirable features in these drills, but most noticeable is the inequality of lip height given in the last column. In practice, feed rates for $\frac{1}{4}$ in. diameter drills do not usually exceed 0.010 in. per rev., yet at this value drills A, B, and C would have a very uneven distribution of cut, a condition conducive to poor drill performance and frequent breakage.

It is of interest to note that the small capacity drilling dynamometer mentioned in Quarterly Review, No. 2, was based on the design of Dr. Schlesinger.

D. F. GALLOWAY,
Deputy Director.

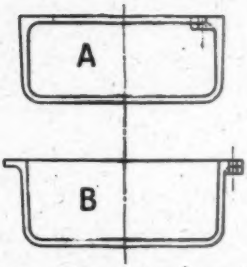
5th January, 1945

DESIGN CONSIDERATIONS FOR DIECASTING

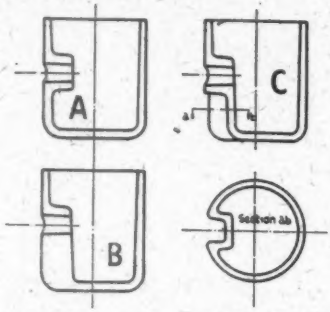
by H. W. Fairbairn

The availability of light alloys at an economical price has increased the need for reliable information on the dimensional accuracies obtainable in the "as cast" condition by the die-casting process.

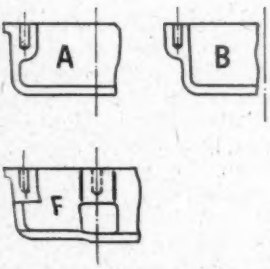
The paper entitled "Design Considerations for Die-casting" which appeared in the November *Journal* included such information. Diagram illustrations of what may be termed, Geometrical hints for the designer of die-castings were also included. As these diagrams and tables were not sufficiently legible for quick reference the author of the paper (Mr. H. W. Fairbairn) has had the whole of these illustrations and tables re-drafted and they are now reproduced in the following pages as a supplement.



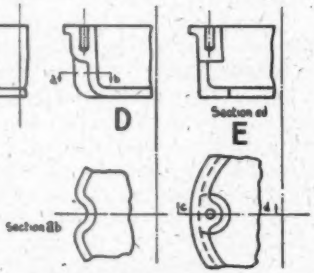
A can be die-cast but would need a collapsible metal core. B with external flange can be produced with single piece core.



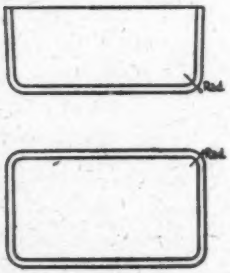
A can be die-cast but would need a collapsible metal core. B can be produced with single piece core but porosity is likely to occur at heavy section beneath boss. C is the ideal alternative where a uniform metal section is preserved.



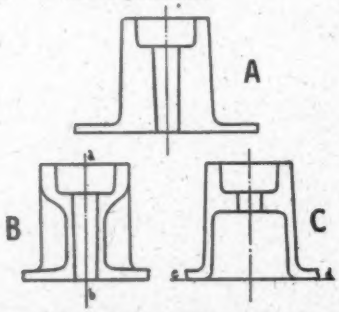
A can be die-cast, but would need a collapsible metal core. B is the preferred alternative with external bosses. C may lead to porosity at heavy section created by extention of boss. D obviates objections referred to at C.



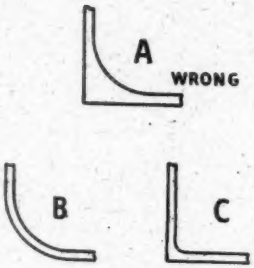
E and F show further alternative methods of dispensing with undercut boss and heavy local sections when bottom or side openings respectively can be permitted.



Similar radii at all corners, thereby enabling same cutter to be used to cheapen die costs.

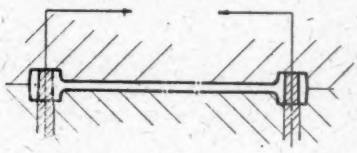


To avoid heavy section at A, boss can be necked and ribbed, when die is jointed at a b, Fig. B, when die is jointed at line c d, Fig. C, the boss construction shown thereat is preferred, as this maintains uniform metal thickness and obviates a long slender core to form small hole.

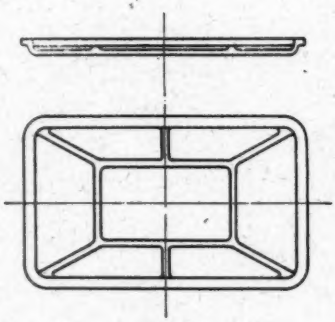


Internal corner radii to be as large as possible consistent with maintaining uniform thickness. When this is not possible as at B. Moderate radius is shown at C.

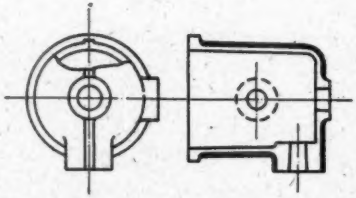
Arrows indicate direction of contraction stresses



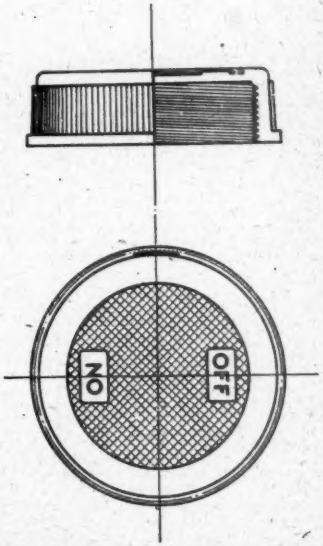
Contraction stresses will bend or even shear small core pins. Cored recesses on one or preferably both sides of the casting between the holes, will protect the cores. The stress is then largely imposed upon the main die members.



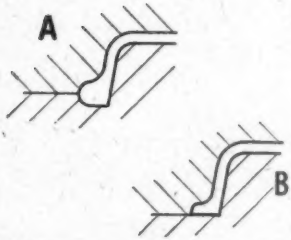
Shallow ribbing will facilitate the running of large, thin section, flat plates.



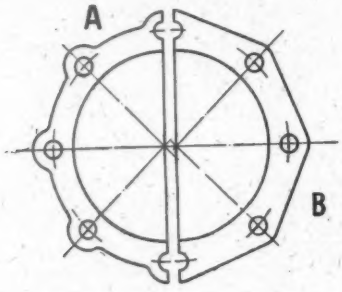
Small external beading at die joint facilitates fettling of castings and localises shear tool marks and will thereby improve general appearance.



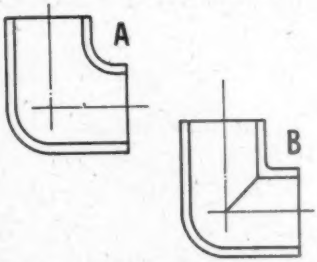
Edge milling only, and not cross: knurling can be cast around the edge of a component. Knurling can however, be included upon the face of the casting as illustrated.
Note.—Fettling bead slightly proud of edge-milling.



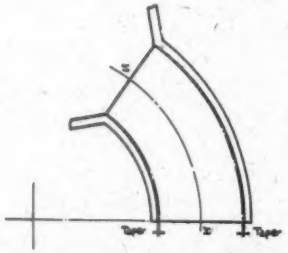
Beading as shown at A requires accurate die matching. This can be obviated as at B with resultant saving in die cost.



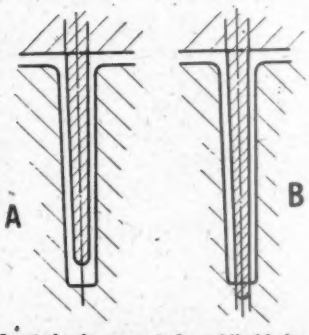
Fettling costs will be reduced if peripheral shape at A is modified to that shown at B.



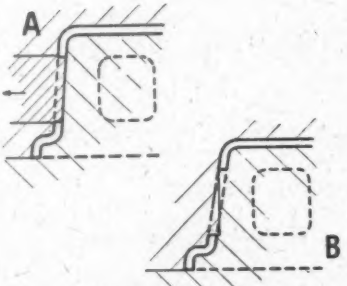
Bend at A with inner radius can be produced only by the use of a sand core, with a sharp corner as at B, bend can be produced with two metal cores.



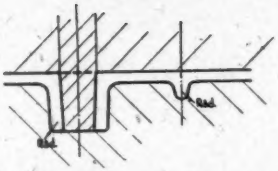
Curved bend can be die cast with metal core rotated on arc xx, providing taper is allowed where indicated.



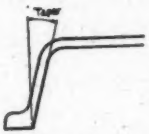
Long slender cores to form blind holes as at A will deform under pressure and heat. This can be considerably minimised when core is located in die at both ends as at B.



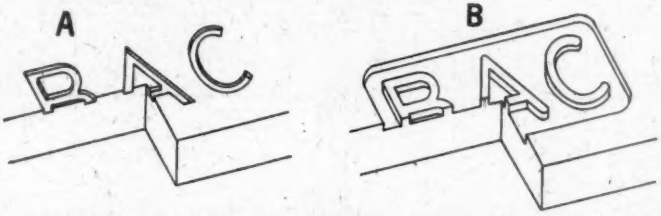
By increasing wall taper, windows can be formed as at B without side core as shown at A, thereby reducing die and operative costs.



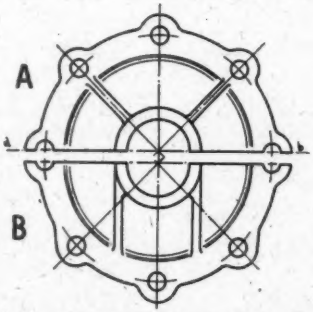
Small radius at the ends of bosses and ribs will prolong die life in the case of pressure castings. For gravity casting, however, corners of bosses should be square to permit the use of vent plugs. Ribs still to be rounded.



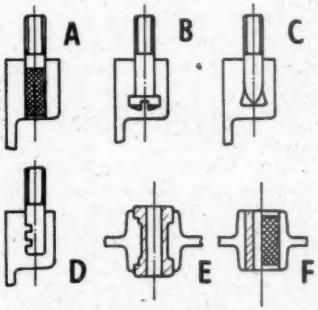
Internal wall tapers to be as generous as possible to increase production rates and minimise distortion of casting. Usually external walls can be parallel with internal to maintain uniform section.



Cast recessed lettering as at A leads to weak projections in the die and is costly to sink. Raised lettering upon a recessed panel as at B, is desired alternative.



When die joint is located at line ab, bosses and ribs as at A need re-arranging as at B to facilitate removal of casting from die.



Showing methods of insert anchorage in die castings.

A Coarse pyramid knurl. B Slotted cheese-head screw. C Insert malformed at anchorage end. D Slotted insert.

Note.—In all of the above instances, threads are terminated just above face of casting to prevent the entrance of metal

E Bush insert reduced at centre and flats milled on one or more sides at one or both ends. F Bush insert, coarse pyramid knurl.

In all of the illustrated examples provision has been made to prevent endwise movement and rotation.

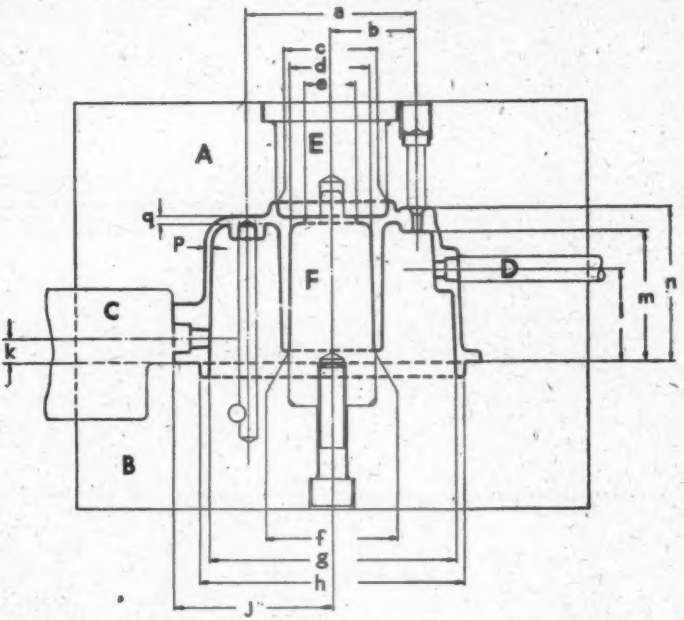
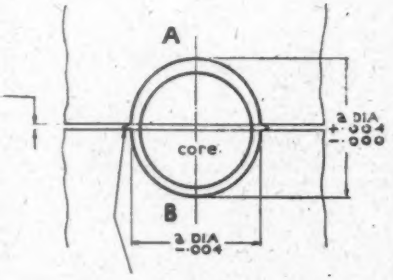


Diagram illustrating section through a typical pressure-casting die. For information regarding effect of die joints and location of cores, etc., upon tolerances refer to next page.

Gap at die joint is not likely to exceed .005".

N.B. Core in diagram is housed in die block B and will therefore remain concentric with outer diameter of casting formed in this block.



Flash formed at gap between die joint.

Diagram illustrating typical effect of imperfect die closure upon the tolerances of a cylindrical casting produced from an axially jointed die.

Tolerances and Tapers

(NOTE.—Unless otherwise stated these refer to pressure castings in aluminium, magnesium and zinc.)

1. Centres of Holes Cored at Right Angles to Parting Line.

Refer to dimensions a and b

$\pm$ .002″ up to 1½″, add $\pm$ .001″ for each additional inch or part thereof. e.g. when b = 3¼″ tolerance will be $\pm$ .004″.

NOTE.—The above is only applicable to centres of holes when cores are located in same die member, when in different members add a further $\pm$ .003″. e.g. when a = 4½″ then tolerance will be ($\pm$ .005)+($\pm$ .003)= $\pm$ .008″.

2. Centres of Cored Holes Cored Parallel to Parting Line.

Refer to dimensions k and l

$\pm$ .003″ at dimension k when core C is located as illustrated in die member B.

— .004″
+ .006″ at dimension l when core D is located as illustrated die member A.

3. Eccentricity Tolerances.

Between diameters e and f = .001″ when core is located at both ends as illustrated at F.

Between diameters d, e, f, to c = .004″ when cores E and F are located to each other.

NOTE.—Above eccentricity tolerances apply only when diameters are ⅜″ minimum and not more than 1.5 diameters long.

Between diameters f g h = .001″ when formed in the same die block as illustrated.

4. Tolerances on Cored Holes and Male Spigots, etc.

Refer also below to Table 7

$\pm$ .0015″ on diameters c, d, e, f, g, h, when not in excess of ¾″ dia., add $\pm$.0015″ for each additional inch or part thereof. e.g., when g = 5½″ dia. tolerance will be $\pm$ .009″.

The above refer to aluminium and magnesium, if in zinc base use :

$\pm$ .001″ on diameters c, d, e, f, g, h, when not in excess of ¾″ dia., add $\pm$ .001″ for each additional inch or part thereof.

5. Tolerances Applicable to Boss Facings, etc.

$\pm$ .002″ up to 1¼″ at dimension m where both faces are formed in same die member.

add $\pm$ .001″ for each additional inch or part thereof.

$\pm$ .006″ up to 1¼″ at dimension n where faces are formed in different members.

add $\pm$ .001″ for each additional inch or part thereof.

$\pm$ .006″ up to 2″ at dimension j where boss face is formed by moving core C.

add $\pm$ .0015″ for each additional inch or part thereof.

6. Tolerances of Wall Thicknesses.

± .003″ at dimension p.
± .004″ at dimension q.

7. Taper in Cored Holes.

Aluminium and Magnesium	1°	included on diameters up to ⅜″.
	1½°	included on diameters up to 1″.
	2°	included on diameters above 1″.
Zinc Base	½°	included on diameters up to ⅜″.
	¾°	included on diameters up to 1″.
	1°	included on diameters above 1″.

NOTE.—Tapers should always be as generous as possible, to facilitate rapid production of castings. In special cases however, the above figures may be reduced, such instances should always be referred to the foundry.

Miscellaneous Data.

(1) Minimum Size of Cored Holes.

(a) For aluminium and magnesium pressure castings :—
⅛″ dia × 3/16″ long.

(b) For zinc base pressure castings :—
1/16″ dia. × 3/32″ long.

NOTE.—The length of blind cored holes should not exceed the following without first consulting the foundry :—

(c) For aluminium and magnesium pressure castings :—
2 diameters long at 3/16″ dia. and up to ¼″ dia.
3 diameters long at ¼″ dia. and above.

(d) For zinc base pressure castings :—
4 diameters long at 3/16″ dia. and up to ¼″ dia.
6 diameters long at ¼″ dia. and above.

(2) Maximum Size of Pressure Die Castings.

Aluminium, magnesium and zinc :—
300 sq. in. projected area at die joint × 10″ deep.

(3) Maximum Weight of Pressure Die Castings.

(a)	Aluminium	10 lb.
(b)	Magnesium	6 lb.
(c)	Zinc Base	26 lb.

Research Department: Production Engineering Abstracts

(Prepared by the Research Department.)

NOTE.—*The Addresses of the publications referred to in these Abstracts may be obtained on application to the Research Department, Loughborough College, Loughborough. Readers applying for information regarding any abstract should give full particulars printed at the head of that abstract including the name and date of the periodical.*

HEAT TREATMENT.

The Nitriding of High-Speed Steel. (*Machinery, 7th December, 1944, Vol. 65, No. 1678, 4 pp., 2 figs.*).

It has been found that, in many cases, the application of a nitriding treatment for high-speed steel cutting tools will improve their life. Two processes are described.

BELTS AND ROPES.

Dual Belts, by H. S. Jude. (*Power Transmission, 15th December, 1944, Vol. 13, No. 155, 6 pp., 5 figs.*).

Part 2. Caterpillar belts made for specific purposes, e.g., for service in dusty conditions. Method of making, and jointing. V-section ropes to replace round cotton ropes.

FURNACES.

Recent Developments in Industrial Furnaces, by H. C. Hottel. (*Machine Shop Magazine, December, 1944, Vol. 5, No. 12, 4 pp.*).

This article is a summary of papers read at the last semi-annual convention of the A.S.M.E. Heat transfer, furnace materials, process control, combustion, and other factors are discussed.

COOLANT AND LUBRICANT.

Testing Lubricants and Bearing Materials, by V. H. Brix. (*Aircraft Engineering, December, 1944, Vol. XVI, No. 190, 2 pp., 3 figs.*).

A description of a useful Rolls-Royce testing machine, with which test pieces of any material can be run with any oil using any desired plate of journal steel, under controlled conditions of load, speed and temperature.

ELECTRICITY.

Magnetising and Demagnetising, by H. E. Hutter. (*Mechanical World, 22nd December, 1944, Vol. 116, No. 3025, 3 pp., 4 figs.*).

The author describes production methods for treating magnetic equipment, and for reducing incidental magnetism accruing in manufacturing processes.

EMPLOYEES AND APPRENTICES.

The Mechanical Engineer and His Training, by S. H. Stelfox. (*Engineering, 24th November, 1944, Vol. 158, No. 4115, 2 pp.*).

Part II : Mechanical engineering makes no organised attempt to attract suitable men. Engineering as a trade is fed by boys who intend to remain tradesmen. Engineering as a profession is fed by boys who can get preferential treatment later on, and the normal professional supply is artificially side-tracked into occupations more widely recognised as "professions." The national loss from this restriction of recruits is probably very serious. The present bursary schemes do not fit in properly, as there is little prospect of proper practical training, or adequate opportunity later on for the graduates. Nothing can be done satisfactorily without the active co-operation of industry. Boys leaving school at 17 or 18 should go to the workshop and pass gradually forward to part-time and full-time courses carrying a degree. The satisfactory completion of the course should virtually guarantee a start at a reasonable salary and a chance of promotion.

Apprenticeship for a Skilled Trade, by F. Twyman. (*Brochure, February, 1944, 70 pp. Published by C. Griffin & Co., Ltd., 5s.*).

Chapter (1) outlines a 5 years apprenticeship scheme for optical instrument making in the London district (4 years for those after whole course at L.C.C. Engineering Day Training School) ; (2) "Considerations on which Scheme is based" includes preliminary training syllabus, training in other countries, etc. An appendix by H. N. Knight deals with "Apprentices and the Law."

(*Book Review communicated by the British Non-Ferrous Metals Research Association*).

FOUNDRY, ETC.

War-Time Developments in Whiteheart Malleable Iron, by G. R. Webster. (*Engineering, Vol. 158, No. 4118, 4 pp., 13 figs.*).

War created unusual demands for materials possessing properties akin to cast or forged steels in quantities which could not be met at that time by the steel industry. The manufacture of various types of caterpillar tracks from malleable iron produced foundry problems, as track links are not machined except for the reamering out of the pinholes. It is essential that the dimensions of the track links should vary only within very small limits ; this requires considerable care, and the necessary manufacturing processes are fully described. Metallurgical problems of heat-treatment and structure are also discussed with the aid of microphotographs.

Foundry Technology and Profits, by A. J. Edgar. (*Machinery-Lloyd, 23rd December, 1944, Vol. XVI, No. 26, 4 pp.*).

The author first deals with the necessity of correct use of existing methods and knowledge, and then goes on to consider how competition due to the replacement of cast iron by other materials, particularly light alloys, can be met.

The Production of Gray Iron Castings in Metal Moulds, by C. English. (*Eng. Digest, September, 1944, Vol. 5, No. 9, 3 pp. Abstract translation from Giesserei, August, 1943, Vol. 30, Nos. 16/17, 9 pp.*).

Iron castings varying in thickness from $\frac{1}{8}$ in. to $\frac{3}{4}$ in. and in weight from

2 oz. to 100 lb. are made in alloy cast iron moulds. Mould life varies from 3,000 to 10,000 castings.

(*Communicated by the British Non-Ferrous Metals Research Association*).

"Hydro-blast"—A New Process for Cleaning Castings. (*Mechanical World, 22nd December, 1944, Vol. 116, No. 3025, 3 pp., 4 figs.*).

This is a powerful, dust-free method, incorporating sand improvement and recovery. A gun, easily handled by one man, projects a fine stream of sand and water against the casting at high velocity. The removed sand and waste water pass through the floor of the room into a sump, from which the sand is picked up in a flowable condition and pumped to counter-flow classifiers.

JIGS AND FIXTURES.

Air-Operated Fixtures. (*Machine Shop Magazine, December, 1944, Vol. 5, No. 12, 7 pp., 10 figs.*).

The use of compressed air for: a drilling machine head and drill jig; a milling fixture; and a fully automatic feeding, clamping and ejecting fixture.

MACHINING AND MACHINE TOOLS.

Machine Tools and the Cutting Process, Parts I and II, by M. Littmann. (*The Machinist, 9th, 16th December, 1944, Vol. 88, Nos. 35, 36, 4 pp., 3 figs.*).

Part I. Present development of the cutting process is due to: (1) The introduction and development of cemented carbides. (2) The application of the wider knowledge of the cutting process. (3) The introduction of new metals and other materials to be cut. It was originally held that the much greater hardness of cemented carbides was alone responsible for their better cutting performance; but other factors have since been discovered, e.g., the higher the temperature of the chip the better the cutting performance. On account of the properties of carbides, tools should be designed to take full advantage of them and not merely follow older types. The cutting process can be regarded as consisting of two parts, the parting of the chip and its deformation, and these are described. Three different improvements have been applied recently, viz.: (a) Double or combined top rake; (b) Negative top rake; (c) Chip breakers.

Part II. As the result of investigations, their effects on the cutting process, and their application have been determined and are herein described.

Swiss Machine Tool Construction, Parts II and III, by Prof. Mettler. (*The Engineer, 17th, 24th November, 1944, Vol. CLXXVIII, Nos, 4636, 4637, 5 pp., 13 figs.*).

Part II. A precision surface grinding machine has been developed with great freedom from vibration. The plain bearings of the grinding spindle are air cooled, and the whole machine is notable for careful layout. A special internal thread grinding machine grinds an internal thread with adjacent cylindrical or tapered bores and plane surface of thread gauge rings at one setting. Another special grinder is a profile grinding machine which has become most indispensable for making tools and gauges in the engineering and watch-making industries. An example of die grinding on this machine is shown. A semi-automatic profile milling and grinding machine is also described with examples of work produced. Two special automatics for thread cutting are mentioned. The use of presses for straightening, drawing and stamping, etc.

is well known, but the oil-operated press is also economically suitable for broaching and slotting work, and a surface broaching application is shown.

Part III. Gear wheel-making machines include machines for cutting gears with curved teeth on spur wheels. This curve form of tooth represents another solution for obtaining extra-high speeds with big outputs. The possibilities of improving most machine tools are in general not exhausted until they have been equipped with all the suitable accessories. Full attention must also be devoted to correct tool grinding. Backing-off grinding apparatus, with and without centres, is a valuable accessory which can be fitted on any tool-grinding machine. To increase the economy of boring machines, two special accessories have been developed, a facing and boring head and a thread-cutting apparatus. Pressing by means of hot and cold presses is of great economical importance, and the Swiss machine tool industry has taken up this branch of work successfully. The range covered by the presses intended for cold forming comprises presses for making cups and bowls, presses for nuts, and presses for washers. For hot forming there are presses for making nuts and presses for shaping from bar material parts up to 50 mm. in diameter.

Deflections and Chatter in Machine Tools, Parts I and II, by G. E. Heiber. (*The Machinist, 16th, 23rd December, 1944, Vol. 88, Nos. 36, 37, 3 pp., 8 figs.*).

Part I. The author strongly criticises " rule of thumb " methods of machine tool design, using lathe design as an example.

Part II. He particularly stresses the adverse effects of the torsional deflection of drive shafts, and suggests means of investigating and overcoming it.

Hydraulic Transmission of Power for Machine Tools, by H. C. Town. (*Power Transmission, 15th December, 1944, Vol. 13, No. 155, 7 pp.*).

Advantages of hydraulic operation are : (1) an infinite number of speeds or feeds between the maximum and minimum, (2) quick reversal without shock, (3) quiet operation and long life due to components working in oil, (4) low power consumption, and (5) safety. Gear type pumps can be used, but for heavier duty the variable delivery pump is more satisfactory and prevents waste of power. Advantages over electrical drives are the wide speed ranges and constant horse power. The author outlines the information required for design purposes, then deals in turn with applications to lathes, turret lathes, drilling and boring machines, milling machines, precision finishing machines, honing machines, reciprocating machine tools, broaching machines, and presses.

Users Agree on Proposed Machine Tool Improvements. (*The Machinist, 2nd December, 1944, Vol. 88 No. 34, 2 pp.*).

Further answers to ten questions on machine tool improvement given in a previous article.

Profile-turning Lathe Machines Camshafts. (*The Machinist, 9th December, 1944, Vol. 88, No. 35, 2 pp., 3 figs.*).

Description of a special Scrivener machine employing copy generating.

Aid to Accurate Machining. (*Production Engineering Bulletin, December, 1944, Vol. 3, No. 25, 2 pp., 2 figs.*).

The fitting of an electrical sizing device to a lathe reduced scrap from 20% to 2%. This apparatus can be applied to a variety of machine tools, and is capable of controlling the size of the work to one-ten-thousandth of an inch.

Using Negative-angle Milling Cutters. (*Machine Shop Magazine, December, 1944, Vol. 5, No. 12, 4 pp., 2 figs.*).

British experience with milling cutters having negative rake and helix angles is described and results of tests are tabulated. Points regarding cutter, machine, and jig and fixture design are discussed.

Using Negative Rake Tools in Aircraft-parts Production, by J. Q. Holmes. (*Mechanical World, 8th December, 1944, Vol. 116, No. 3023, 3 pp., 3 figs.*).

Negative rake cutting was investigated for high tensile steels (e.g., Cr-Mo and Cr-Ni-Mo), and the increased production and improved quality amply warranted its adoption. Putting the new process into production met with considerable resistance from management and operators, but negative rake tools are now used for milling, turret-lathe, and precision boring work. The milling operations are described, and details given of operating precautions that must be taken, feeds, speeds, tooth load and number of teeth.

CHIPLESS MACHINING.

Design of Dies for Rubber-die Press Work. (*Machinery, 28th December, 1944, Vol. 65, No. 1681, 4 pp., 10 figs.*).

The formation of flanges, either by simple bending or forming, comprises the great majority of rubber-die press operations. Points of importance in designing the tools are given. The requirements for a good die material are discussed, and attention is given to the use of zinc and impregnated hardwood dies.

Limits of Formability for Sheet Magnesium Parts, by P. A. Nagy. (*Product. Eng., August, 1944, Vol. 15, No. 8, 5 pp.*).

Presents forming qualities of four Mg alloys (Dow Chemical Jlh, and Ma, American Magnesium AM52SH and AM52SO) by the Guerin, i.e., rubber-pad forming method, and gives recommendations for designing. Refers to flanges, joggles, beads and lightening holes. Tables include recommended bend radii, shearing stresses for holes and cupping depths for flanged holes. See also article by Resos on hot forming of Mg alloy sheets, noted in B.N.F. Bulletin 185, November, 1944, p. 302, referring to the same alloys.

(*Communicated by the British Non-Ferrous Metals Research Association*).

Hot-forming Magnesium. (*Machinery, 14th December, 1944, Vol. 65, No. 1679, 4 pp., 5 figs.*).

Magnesium plates $\frac{1}{4}$ inch thick are formed hot to required contours in a stretching press.

MANUFACTURING METHODS.

Motion Study. (*Production and Engineering Bulletin, December, 1944, Vol. 3, No. 25, 3 pp., 3 figs.*).

Part II : This describes, with the aid of photographs, the application of motion study to the manufacture of a valve holder involving these operations ; (1) enclosing a ceramic moulding between two rings projection-welded together, (2) inserting the contacts and ferrule, (3) tinning the contacts, (4) visual inspection, (5) checking the strength of the contacts, (6) stamping and counting, and (7) packing.

The Motion Study Society of Great Britain, by The Rt. Hon. Lord Marley. (*Machine Shop Magazine, December, 1944, Vol. 5, No. 12, 3 pp.*).

The author, who is associated with the M.A.P. Production Efficiency Board, outlines the history of the development of motion study in Britain and stresses its part in post-war production.

Selecting Production Methods for Small Parts, by F. P. Peters. (*Metals and Alloys, July, 1944, Vol. 20, No. 1, 16 pp.*).

A useful compendium. Description of methods and forms (permanent mould, sand, die, plaster mould, and precision investment castings; forgings; pressings; cut extrusions; sectioned tubing; powder metallurgy; stampings; screw machining; spinning; impact extrusions; weldings or brazings). This is followed by long tables showing general relation of method of production to design, cost and properties of product, and finally by a table showing methods of production of small parts used for common metals and alloys. Bibliography.

(*Communicated by the British Non-Ferrous Metals Research Association*).

Hercules Sleeve-valve Engine Production. (*Machinery, 7th, 14th, 28th, December, 1944. Vol. 65. Nos. 1678, 1679, 1681, 23 pp., 37 figs.*).

General features of the engine are outlined, and manufacturing methods described. Among the operations dealt with are: (1) On the sleeve; heat-treatment, rough machining, internal and external centreless grinding, profiling, punching the ports, honing the external diameter and the bore simultaneously, lapping and brushing, and dimensional inspection. (2) On the light alloy cylinder barrel; roughing, finning, finish-boring, and lapping the bore. (3) On the cylinder head; roughing the two halves, machining the mating surfaces, shrinking together, and final machining of the unit.

The Gypsyqueen II, by J. A. Oates. (*Aircraft Production, December, 1944, Vol. VI, No. 74, 12 pp., 28 figs.*).

Part III. The crankcase top cover, in spite of its apparent simplicity, presents many difficult machining problems. This instalment deals mainly with special fixtures introduced to overcome them and ensure interchangeability. Machining the camshaft, gears, and final engine assembly and test, are also described.

The Sigma Comparator and the System of Limits and Fits Used in its Manufacture. (*Machinery, 21st December, 1944, Vol. 65, No. 1680, 4 pp., 3 figs.*).

The makers have found it convenient to use only a limited number of tolerances and fits, and sizes of shafts. Most of the fits and tolerances are in accordance with B.S.S.164, but others have been devised to meet particular requirements. Thus, for a high precision running fit a group of B holes is graded into three sub-groups, and shafts from each sub-group are assembled with holes from the corresponding sub-group. For the purpose of reducing tooling and gauging equipment, preferred sizes of shafts and holes are used.

Rapid Production of Finned Tubes, by A. G. Arend. (*Machinery 21st December, 1944, Vol. 65, No. 1680, 2 pp., 1 fig.*).

A discussion of various methods.

Handbook on Designing for Quantity Production, by H. Chase (Editor). (*Book, 1944, 517 pp., McGraw-Hill Book Co. £1 15s.*).

A general consideration and comparison of production by die casting, sand casting, stamping (from sheet), screw-machining, die-forging and heading, this survey of metallic products being rounded off by a discussion on moulding of plastics.

Book Review communicated by the British Non-Ferrous Metals Research Association).

A New Microhardness Tester, by Professor Ragnar Woxen. (*Industrial Diamond Review, November, 1944, Vol. 4, No. 48, 5 pp., 12 figs.*).

The various static hardness testing methods are discussed and different hardness numbers are deduced as well as their interrelationship and that between them and the cold-working capacity of the specimen. A new microhardness tester is described with which both the impression difference due to various initial loads and the test loads ranging from a few gm. up to 1 kg. and the corresponding impression diagonal or diameter can be tested. From these values it is possible to work out Vickers numbers H_{Bv} and the Woxen number H_W by means of equations or nomograms and to determine the cold-working capacity not only for metals of any hardness, but also for certain crystals and for very thin, hard surface layers, etc.

MEASURING METHODS AND INSPECTION.

Three Dimensional Surface Plate Cuts Labor Costs 40 Per Cent, by Earl M. Barden. (*The Machinist, 2nd December, 1944, Vol. 88, No. 34, 3 pp., 3 figs.*).

The universal setting fixture helps in positioning locators accurately and economically on large aircraft pipe fixtures replacing the costlier methods requiring a level or transit.

Small Batch Quality Control. (*Production and Engineering Bulletin, December, 1944, Vol. 3, No. 25, 6 pp., 12 figs.*).

Methods of an engineering firm producing components in batch quantities of 200 to 1,000, where the usual rules for determining control limits cannot be employed because the order would be completed before the control limits could be established.

PHOTOGRAPHY, RADIOGRAPHY, ETC.

The Electron Microscope for Metals, by R. G. Picard and P. C. Smith. (*Mining and Metallurgical Engineering Newsletter, October, 1944*).

A long abstract from Metals and Alloys, September, 1944. The authors of this article present a general description of the instrument, describe and illustrate some of its applications in metallographic work and outline its use in diffraction studies. Sizes, shapes, and contours of particles unobservable with the light microscope were sharply revealed with the electron microscope. However, it could not be used for the direct study of metal surfaces. The penetrating power of electrons is so small that the usual thin sections were opaque to the beam, and spectacular reflection of electrons from surfaces does not take place. However, by virtue of new techniques, new and fundamental information has been gained concerning crystal structure in metals, grain biundaries, phase distribution in alloys, effects of abrasion, corrosion and etching, and other fundamental characteristics and properties of metals.

(*Communicated by the U.S. Office of War Information, London*).

Microradiography—New Tool of Metallurgy, by S. E. Maddigan and B.R. Zimmerman. (*Mining and Metallurgical Engineering Newsletter, October, 1944*).

Radiographic examination of metals by X-rays, commonly used to detect hidden flaws, has lately been extended to reveal microstructures as well. This new tool is as yet insufficiently appreciated and merits serious consideration by metallurgists. Micrographs made of polished, etched metal surfaces in the ordinary way reveal crystalline structures and thus yield invaluable information about the metals examined. When X-rays are transmitted through thin, polished, metal sections and then allowed to impinge on a photographic plate of extremely fine grain, the resulting radiograph can be magnified optically to reveal both micro-scopic flaws in the metal and the distribution of the various alloy constituents in it.

(*Communicated by the U.S. Office of War Information, London*).

PLASTICS AND POWDER METALLURGY.

Tolerance for Moulded-plastic Screw Threads, by J. Butler. (*Machinery, 28th December, 1944, Vol. 65, No. 1681, 4 pp.*).

In standard metal-thread tolerances, variations are recognised as due to errors in pitch, thread angle, diameters (major, effective and minor), and the wear of thread cutting tools. In plastics all these factors must be taken into account, and in addition (a) plastics are far less stable than metals ; (b) threads are produced from moulds which themselves are cut by metal-cutting methods, with tolerances ; (c) the shrinkage of the material results in a moulded thread which is smaller than its metal mould not only in diameter, but in length. Their implications are discussed, and a system of tolerances is dealt with in detail.

Forming Aircraft Parts from Phenolic Plastics. (*Machinery, 21st December, 1944, Vol. 65, No. 1680, 5 pp., 8 figs.*).

Plastics weigh only half as much as aluminium, and have been proved sufficiently serviceable under tests of limited strain and in actual service, to warrant their acceptance as aircraft material. Typical applications, and the technique employed at North American Aviation, Inc., in the manufacture of phenolic-plastic parts by the thermo-elastic process are described.

Powder Metallurgy, (A)—Manufacturing Methods and Limitations, by J. H. Bull, **(B)—Applications, Uses and Trends,** by J. H. Robinson. (*The Australasian Engineer, Science Sheet, 7th September, 1944, 6 pp., 7 figs.*).

(A). Particle shapes and production methods. The effect of particle size. A typical sintering process. Future prospects.

(B). Limitations of powder metallurgy. Use with metals beyond the reach of conventional melting practice. Graphite and porous bronze bearings. Combination of immiscible metals. Metal coatings. Other applications.

SHOP MANAGEMENT.

Management in Great Britain and the United States, by D. Tiranti, (*Mechanical World, 8th December, 1944, Vol. 116, No. 3023, 2 pp.*).

This article reviews the Cotton Textile Mission's Report and its potential application to the engineering industry. Particular attention is paid to production per man-hour.

SMALL TOOLS.

Milling Cutters and How to Use Them, by M. Martellotti. (*The Machinist, 2nd, 16th, December, 1944, Vol. 88, Nos. 34, 36, 9 pp., 5 figs.*).

Part I. This article is the first of a series based on years of research by one of the largest and most progressive manufacturers of milling machines. It deals with the general properties of commonly used cutter materials in the carbon steel, H.S.S., cast non-ferrous material, and sintered carbide groups.

Part II. This describes heat treatment, cold treatment, and chromium plating.

Tool Control Practiced at the Puget Sound Navy Yard, by W. E. Ainsworth. (*Mechanical Engineering (U.S.A.), October, 1944, Vol. 66, No. 10, 7 pp., 18 figs.*).

Centralized tool control has many advantages, including increased production, longer tool life, and correct tool conditions. A brief description is given of reconditioning twist drills and chisels, tool-and-die making and repair, tool grinding, storage of tools, and tool control. Special attention is given in this plant to special tool grinding machines.

Sub-Zero Cooling Benefits Discussed by Experts. (*The Tool Engineer, (U.S.A.), 5 pp., 5 figs.*).

The discussion is concerned mainly with the use of low-temperature treatment for gauge and high-speed steels. Under proper conditions the austenite-martensite transformation is extended, and trouble due to growth of gauge steel may be prevented. The object of sub-zero treatment of high speed steel tools is to give better performance, but records of individual jobs with super-cooled tools show variable results. However, the process produces stability through relieving of stress, and tools are less liable to check or crack in grinding. Though better tool performance cannot be consistently obtained in all cases, freezing seems in no way detrimental to cutting tool life.

Tool Steels, by J. P. Gill. (*577 pp., American Society for Metals, Cleveland, U.S.A., 1944, $6*).

Written mainly for users, this book presents existing information on the more common types of tool steel. The first half deals with manufacture, classification, testing, properties and selection, heat treatment, and purpose and effect of alloying elements. The subsequent chapters deal in detail with the various types of tool steel (carbon ; chromium and chromium vanadium ; low-chromium-nickel-molybdenum and manganese ; oil hardening non-deforming ; silicon ; tungsten finishing ; graphitic ; chromium die steels for cold work ; die steels for hot work ; high speed steels). There is a select bibliography of over 500 references.

(*Book Review communicated by the British Non-Ferrous Metals Research Association*).

SURFACE TREATMENT.

Fatigue Life of Stressed Parts Increased by Shot Peening, by D. C. Turnbull. (*The Machinist, 16th December, 1944, Vol. 88, No. 36, 4 pp., 4 figs.*).

As an outgrowth of a cleaning process, shot peening is now used to add service life to many types of products. Tests and experiments show how to get the best results. Methods have been developed to determine the intensity of peening.

Infra-Red Baking. (*Machinery Lloyd, 23rd December, 1944, Vol. XVI, No. 26, 3 pp., 2 figs.*).

Recent years have seen a considerable development in the use of infra-red baking for paints, etc. This article reviews the subject generally. It indicates the underlying principles; the different methods, utilising gas and electric heating; and the advantages and limitations of its application.

The Pickling of Steel—Part II, by E. W. Mulcahy. (*Sheet Metal Industries, December, 1944, Vol. 20, No. 212, 9 pp., 19 figs.*).

Timber tanks, lead-lined tanks, and rubber-lined steel tanks, continuous strip mill pickling tanks, washing tanks, brick and concrete tanks for heavy batch pickling, spray pickling plant.

TRANSPORT.

War in the Tropics. (*Production and Engineering Bulletin, December, 1944, Vol. 3, No. 25, 8 pp., 11 figs.*).

Military authorities in the tropics have expressed serious concern that much equipment produced for the European theatre of war cannot be used in the Far East. Reports have made it quite clear that standards of preservation and packaging for temperate climates seldom withstand the rigorous conditions in the tropics. British and American Service authorities have now established three main types of packs, and these are described.

WELDING, BRAZING AND BONDING.

Production in the Fabricating Shop, by F. Koenigsberger. (*Welding, December, 1944, Vol. XII, No. 13, 8 pp., 22 figs.*).

Inspection procedure. The article suggests how to apply to the fabricating shop methods of inspection whose value for technical and economical efficiency in the machine and fitting shop has been proved and established. In addition to the continuous supervision of foremen and chargehands, there should be regular inspection. The author proposes a rigid inspection system at all stages of manufacture, including: drawing raw material, preparation of plates, machining of detail components, assembly of the prepared parts, execution of welds, and heat treatment.

Oxy-Acetylene Welding, by F. Clark. (*Sheet Metal Industries, December, 1944, Vol. 20, No. 212, 9 pp., 15 figs.*).

Part I. A study of problems associated with design and technique.

The Application of Arc Welding to Turret Lathe Production, by H. A. Oldenkamp. [*Machinery (New York), September, 1944.*]

Practice at the works of the Warner and Swasey Co. is described. Stages in the redesign of a motor base as a welded structure are discussed. Cast-iron and welded steel bar-feed stands and belt guards are contrasted. Work is speeded up by the use of jigs and fixtures for welding. Easily machined steels are not always most suitable for welding. The opinion is given that welding seriously warrants consideration in all machine tool plants.

(*Communicated by Machine Shop Magazine*).

Welding in the Construction of Punches and Dies, translated by P. Grodzinski. (*Mechanical World, 8th December, 1944, Vol. 116, No. 3023, 3 pp., 8 figs.*).

Welding technique brings advantages for " one-off " production and special designs, since the tool can be made lighter and the material consumption is reduced by the use of mild steel instead of cast iron ; scrap material can be used with advantage and patterns are no longer necessary. Eight examples of welded punches and dies are described.

" Two-Tone " Arc Welding, by J. A. Cunningham. (*Welding, December, 1944, Vol. XII, No. 13, 2 pp., 1 fig.*).

This new technique for the rebuilding of worn surfaces consists of welding in the conventional manner with a mild steel electrode in the holder while a cast iron or high carbon steel auxiliary filler rod is held adjacent to the arc. Two to three times more metal can be applied per hour than by ordinary methods.

Low-Frequency Induction Heating, by O. Kreisel. (*The Welding Journal, Vol. 23, No. 8.*).

The intense heat which is concentrated in one spot on a metal surface by the electric welding arc often sets up internal strains which create a danger of warping and cracking. Experience has shown that the answer to this problem is to prepare the metal to receive and absorb these strains by pre-heating the area which surrounds the weld. In such preheating, the temperature to which the metal should be raised depends on its composition and also upon the type of weld to be made. In any case it is greatly desirable that this temperature be closely controlled. The author deals with practical application of low-frequency induction heating for preheating and normalising in connection with welding and other heating developments.

(*Communicated by Welding*).

The Quality of Resistance Flash Welds of High Tensile Steels, by F. Bollenrath and A. Cornelius. (*L.F.F., 28th February, 1944, Vol. 21, No. 1.*).

An R.T.P. abstract. Experiments were carried out, mainly with two Cr-V steels, on plates of various thickness. Joints were subjected to various heat treatments and then mechanically tested.

(*Communicated by Aircraft Production*).

Tooling for Magnesium Welding, by Kenneth L. Kime. (*Iron Age, Vol. 154, No. 9*).

Allowance for expansion and contraction of magnesium entails special requirements for rigid supporting of the welded structure. In designing jigs and holding devices, the problem is not only to relieve welding strains but to accommodate also for another warping factor, the locked-in strains resulting from prior operations done on the magnesium such as rolling, braking, hot and cold forming and heat treating. Towards this end, the author, presents an analysis of clamping devices, stiffeners and other tool elements, and illustrates the adaptability of heavy drop hammer dies for the bases of the welding jigs.

(*Communicated by Welding*).

Copper Brazing as a Production Tool, by C. L. Hibert. (*Automotive and Aviation Ind., 1st August, 1944, Vol. 91, No. 3, 15 pp.*).

Author surveys principles of copper brazing including furnace atmosphere ; cleaning of surfaces to be brazed ; design for Cu brazing ; advantages over other methods ; furnace brazing alloys ; replacement of steel stampings by forgings through use of Cu brazing ; furnace brazing ; and cycle brazing.

(*Communicated by the British Non-Ferrous Metals Research Association*).

Radio-Frequency Technology in Wood Application, by G. F. Russell and J. W. Mann. (*Transactions of the A.S.M.E. (U.S.A.), August, 1944, Vol. 66, No. 6, 5 pp., 15 figs.*).

As a basis for understanding the principles involved in applying radio-frequency heating to the resin-bonding of wood, the authors explain certain fundamentals of radio theory which are involved. A particular quality of the radio-frequency field is its selectivity which results from the tendency of the field to follow the most conductive path between electrode extremities. Originally operations of bonding materials by this means placed alternate layers of wood and glue in the field so that the glue lines were established parallel with the electrodes causing the field to be perpendicular to the glue line. More recently it has been established that the normal resin-glue line is more conductive than the wood with which it is associated, and the technique of " parallel bonding " in which the field is parallel with the glue line has been developed. Details of the process, application of radio-frequency heating to specific cases, most efficient electrode arrangements, and results attained are treated comprehensively.

High-Frequency Heating, by W. Nichols. (*Aircraft Production, December, 1944, Vol. VI, No. 74, 6 pp., 15 figs.*).

Radio-frequency heating offers a means of accelerating the bonding of synthetic-resin adhesives, particularly where thick laminated assemblies are concerned, which is free from some of the difficulties attached to more usual hot-press methods. The article reviews various methods of applying the process and describes certain practical applications which have been made in the production of aircraft components in the United States.